HELMHOLTZ

# Connecting astronomical observations with the laboratory

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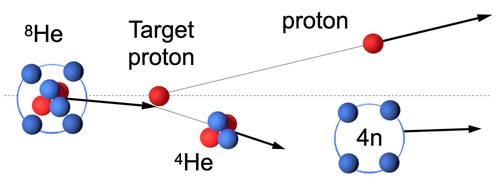
MATTER AND THE UNIVERSE

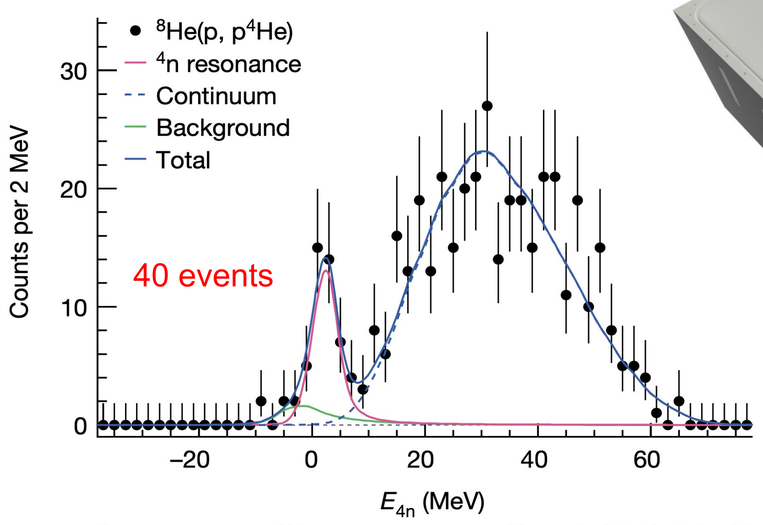
Topic: XXXXX

## Evidence of a correlated free four-neutron system: M. Duer *et al.*, Nature 606, 678 (2022)

Quasifree α-knockout $^{8,6}$He($p$, $p\alpha$)

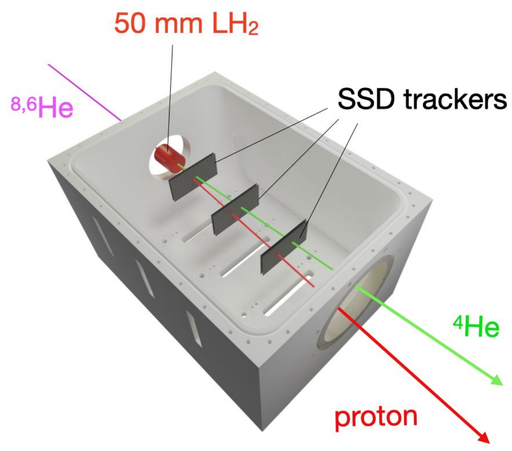
Maximum momentum transfer



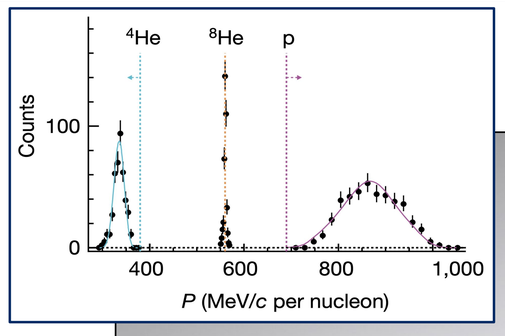

Reaction chamber:

$LH_2$ target with microstrip Si trackers



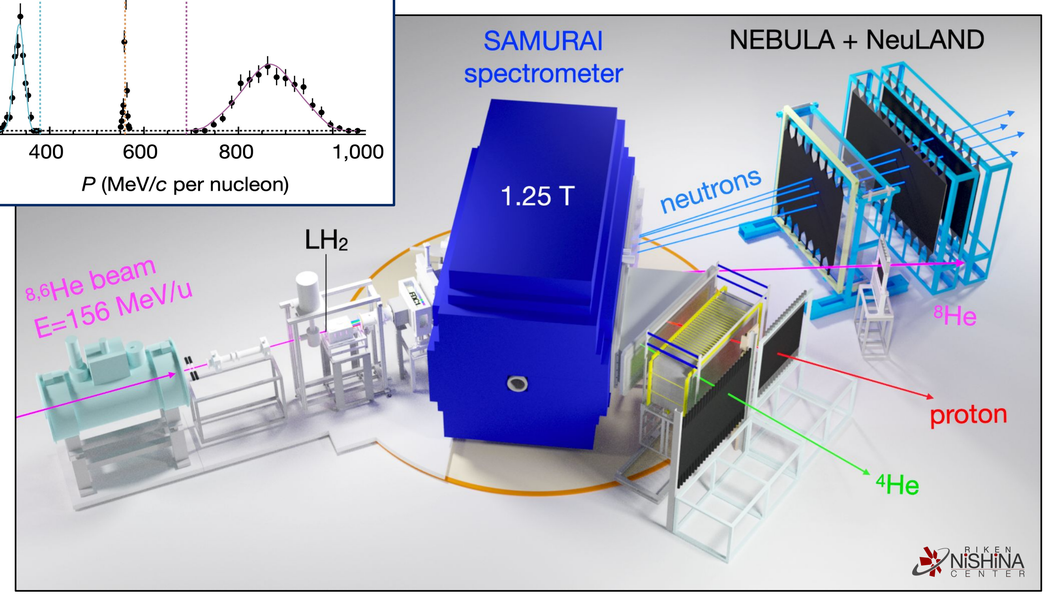

Reconstructing 4n energy:

$$E_{4n} = \sqrt{E_{miss}^2 - \mathbf{P}_{miss}^2} - 4m_n$$




Final state = fast proton + slow $^4$He

→ 180° p-$^4$He CM scattering



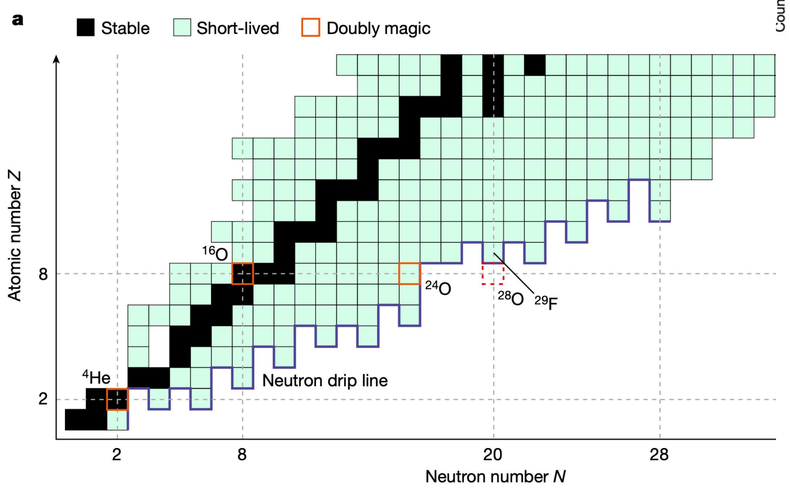

**Resonance-like structure: *E*r = 2.37(0.58) MeV, Γ = 1.75(0.40) MeV**

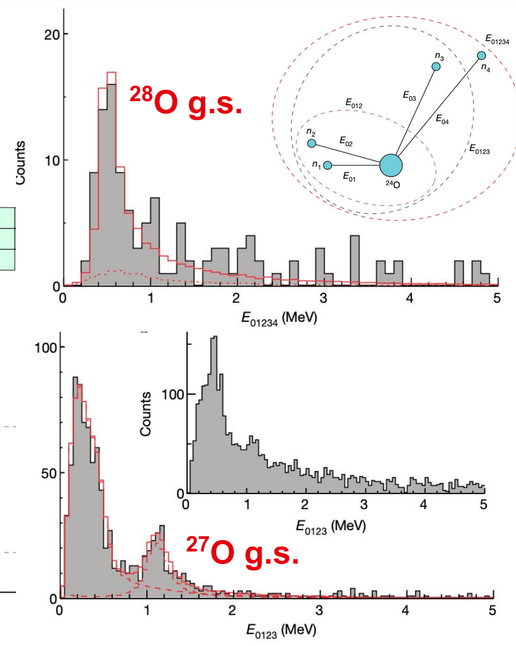
NeuLAND detector for high-efficiency neutron detection at R$^3$B

**Perspective studies of multi-neutron systems @FAIR**

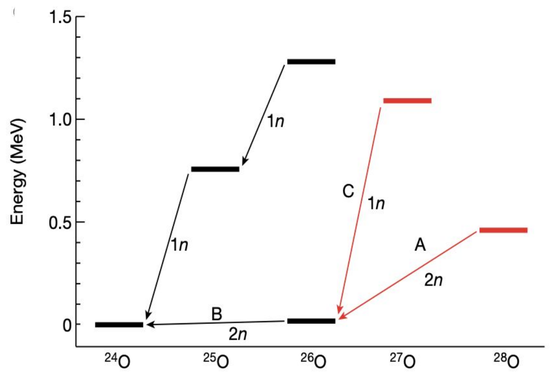
## First observation of $^{28}$O: Y. Kondo *et al.*, Nature 620, 965 (2023)

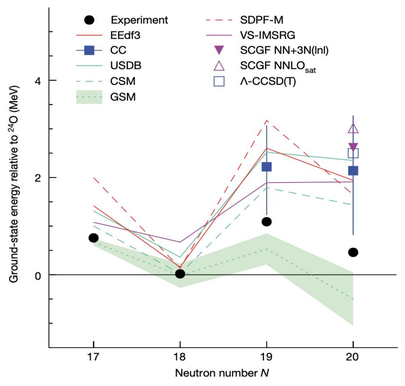
- Beyond the drip line nuclei $^{27,28}$O
- Disappearance of the magic N=20 shell closure
- Knockout reaction: $^{29}$F(p,2p)$^{28}$O → $^{24}$O + 4n




- First invariant-mass measurement with four neutrons
- 5-body relative-energy spectrum: $^{24}$O + 4n
- Observing unbound ground-state resonances in $^{27,28}$O
- Experimental energies are lower compared to theory
- No closed N=20 shell structure confirmed



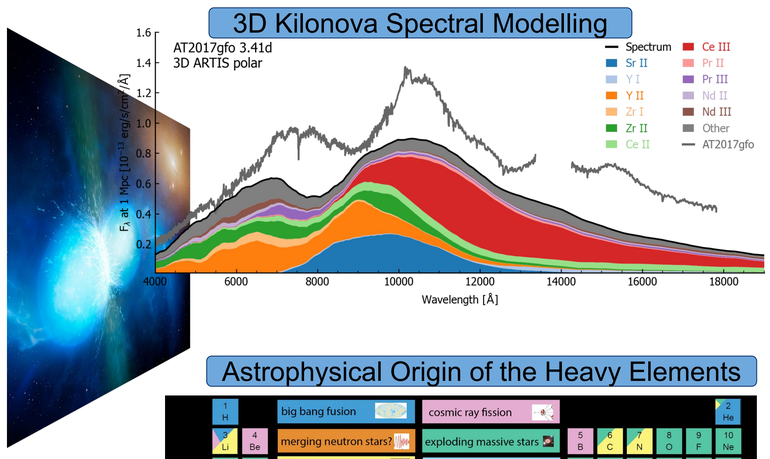




## 3D kilonova spectral modelling: L.J. Shingles *et al.*, ApJ Letters 954 L41 (2023)

**Self-consistent 3D modelling pipeline: connecting astronomical observations with the lab**

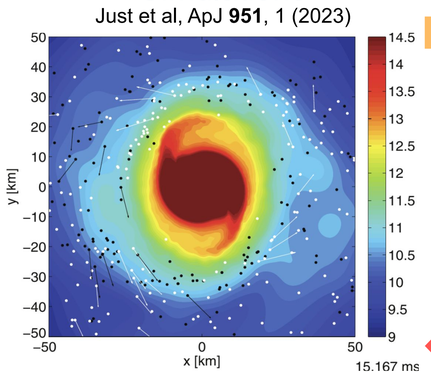
*Determine the underlying physics of the r-process, merger dynamics and EOS (cf. CBM @FAIR)*

- Long-term simulations of all mass ejection channels (milliseconds – seconds)
- Comprehensive nucleosynthesis analysis to determine key nuclear reactions
- NUSTAR experiments @FAIR on key exotic nuclei
- Advanced kilonova modelling allows to identify which specific elements are produced and under which conditions
- Spin-off: Determination of the expansion rate of the Universe ($H_0$) - Hubble tension



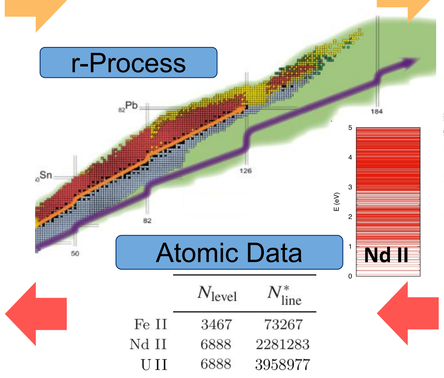

### Hydrodynamical Simulations

Just et al, ApJ **951**, 1 (2023)



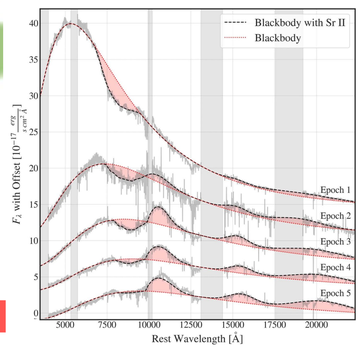

### r-Process Nucleosynthesis & Atomic Data

Flörs et al, MNRAS **524**, 2 (2023)




| | $N_{level}$ | $N^*_{line}$ |
|---|---|---|
| Fe II | 3467 | 73267 |
| Nd II | 6888 | 2281283 |
| U II | 6888 | 3958977 |

### Light curve and spectral modelling




Watson et al., Nature **574**, 497 (2019)
Sneppen et al., Nature, **614**, 7948 (2023)
Shingles et al., ApJL, **954**, 2 (2023)
Collins et al., MNRAS, **529**, 2 (2024)

ERC Starting Grant „GreatMoves“, SFB 881, SFB 1245, Research Cluster ELEMENTS,
ERC Advanced Grant „Kilonova“, Gottfried Wilhelm Leibniz Prize 2022,
ERC Synergy Grant „HeavyMetal“

GSI Helmholtzzentrum für Schwerionenforschung GmbH

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